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ABSTRACT

The National Institute of Education sponsored a conference on the future of research in adolescent reasoning. This report reflects this conference discussion, which focused on: (1) the theoretical basis for research programs in the area of adolescent reasoning; (2) research programs likely to be effective in gathering information relevant to education; and (3) methodical procedures that might foster these research programs. It was found that two major issues face decision makers considering future directions for research on adolescent complex problem solving. The first concerns appropriate theoretical formulations to guide research programs which, unlike Piagetian theory, would be able to offer predictions concerning current educational issues such as transfer, task specific variance and instruction. The second concerns appropriate methodical tools, such as task analysis and multivariate analysis, which gather information to develop the theories. These methodological tools were considered valuable for understanding why and how task information is encoded and why and how conceptual schemes become available to a subject and are activated. Also, it was proposed that by analyzing the likely causes of failure on tasks studied, researchers could begin to understand how to design instruction in adolescent reasoning. (Author/RF)

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# FINAL REPORT

## NIE-SRCD CONFERENCE

## ON FUTURE RESEARCH IN ADOLESCENT REASONING

National Institute of Education Contract No. NIE-P-78-0023

Project Director

Marcia C. Linn
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## The Conference

The NIE sponsored a conference on the future of research in adolescent reasoning. Participants were members of the SRCD panel on adolescent reasoning (Marcia Linn and Pat Arlin, Co-Chairmen; Jonas Langer, Mimi Lou, Steven Pulos, Marlene Scardamalia, Bob Siegler, and Carol Tomlinson-Keasey), several local researchers in the field (Paul Ammon, Robert Hess, Denis Phillips, and Eleanor Willemson), and several observers and graduate students (Susan Chipman, Andrea Lash, Dorothy Piontowski). Discussion focused on the theoretical basis for research programs in the area of adolescent reasoning, research programs likely to be effective in gathering information relevant to education, and on methodological procedures that might foster these research programs.

## What is "Adolescent Reasoning?"

When I tell parents I study adolescent reasoning, the most common response I get is: "Do they?" The field was defined, in a sense, by Inhelder and Piaget's monumental work, and some have gone so far as to jest that as intelligence has been called "what the test measures," so adolescent reasoning is what Inhelder and Piaget measured.

Inhelder and Piaget (1958) categorized adolescent reasoning into two related areas: separation of variables and proportional reasoning. Separation of variables is well illustrated by a recent automobile commercial which argued: "I used to drive my economy car to Sacramento and back to San Francisco and I always returned with half a tank of gas. Now I drive my large luxury car to Sacramento and back and still return with half a tank of gas. Buy a large luxury car." Clearly many variables are uncontrolled in this experiment, including how many times the gas tank was filled.

Proportional reasoning includes the classic problem of "If 6 oz. of mustard cost 33 cents, how much will 10 oz cost?" as well as more abstract applications, such as metaphors (e.g., concrete thinkers use trial and error, but formal thinkers use: (a) instinct, (b) groupments, or (c) planning).

Inhelder and Piaget's book and replications and extensions of this work have focused on a class of tasks which can be called complex problem solving. This imperfectly defined problem class is characterized by a concern for reasoning skills frequently employed in real life situations and sometimes called adult scientific literacy. Clearly ability to control variables is necessary when selecting a new car or when diagnosing which new food is causing a baby's allergy. Proportional reasoning is necessary for selecting the cheapest bottle of ketchup and for predicting how much grass seed is needed for a lawn. Correlational and functional reasoning are necessary to disentangle, for example, the relationship between alcoholism and drunkenness or world population and energy resources. The educational significance of these types of problems is clear. Controlling variables and proportional reasoning are routinely included in adult literacy tests and in consumer science and math curricula.

As educators we need to teach these complex problem solving skills yet, at present, our knowledge of the development of these skills, the transferability of learning from one task to another and the role of individual differences in performance is rudimentary.

In considering the future of research in adolescent reasoning, we must first question whether this area deserves to be specially demarcated. Could the questions addressed by those studying adolescent reasoning be equally well answered by people studying other segments of the population? Is there some special characteristic of adolescence that justifies research geared toward this population? Certainly Inhelder and Piaget's (1958) work in this area

suggests differences between adolescents and other members of our population. In addition, the lack of work with the adolescent population in the past suggests an omission that ought to be redressed. However, the absence of study of a particular area does not justify the need for such study, and a single work suggesting the importance of an area does not necessarily recommend its future consideration. Indeed, many researchers who started with an interest in adolescents have extended their findings either upward in the age range or downward. For example, Siegler at Carnegie-Mellon and Langer at Berkeley are working more with younger children now than with adolescents.

Have researchers following Inhelder and Piaget raised issues or uncovered findings which highlight the importance of this area? Work in adolescence is perhaps characterized more by a diversity of methodologies and a lack of consensus than by any clear findings suggesting important implications for education. Yet educators despair at the thought of providing programs for adolescents, and indeed few educational programs geared specifically for the needs of adolescents have been developed. Textbooks on adolescence focus on social and emotional changes during the period of 12 to 16 years more than they do on cognitive changes likely during this period.

Research conducted on adolescent cognitive abilities suggests that we might better understand social and emotional development by including consideration of adolescent cognitive skills in our thinking. A student at Stanford, Kathy Lewis, is examining choices made by unmarried pregnant teenagers partly in terms of which variables they consider and/or control. Dr. Iris Litt at the Stanford Medical School is looking at adolescent compliance with physician's instructions partly in terms of logical development. Understanding of social development will be fostered by consideration of cognitive development. Cognitive development during adolescence, however, is broadly relevant to future life

tasks and deserves investigation especially from the standpoint of how it can be fostered.

Adolescent reasoning when defined as complex problem solving with an emphasis on real life problems does deserve special consideration. This area of research is likely to provide information relevant to curriculum designers focusing on adolescent problem solving. Research in this area is also likely to further understanding of adolescent social and emotional development just as understanding of social and emotional development will contribute to understanding of cognitive development.

## Theoretical Viewpoints Relevant to Research in Adolescence

Work on adolescent cognitive development has been dominated by Piagetian theory. This domination has placed less emphasis on important educational concerns than is desirable for educational researchers. Educational questions not emphasized in Piagetian theory, the potential relevance of Piagetian theory, and advantages of other theoretical viewpoints are discussed in this section. The work of Inhelder and Piaget (1958) and the accompanying structural theory have guided researchers in exploratory studies of adolescent development. Replications of Inhelder and Piaget's work raised important questions concerning (1) the generality of the experimental results, and (2) the universality of the observed developmental progression (Niemark, 1975a; Levine and Linn, 1977). Let's consider these questions and their implications.

The first question can be stated more precisely as, "Are the experiments selected by Inhelder and Piaget representative of all aspects of adolescent logical thinking, or do they sample a narrow domain?" and, "Do the experiments give information useful for educational decision making?" The experiments in the Inhelder and Piaget book are all based on physical science principles, involve physical variables, and employ manipulative materials. Responses to

the tasks are coded into categories relevant to the Piagetian stages and sub-stages.

The tasks selected by Inhelder and Piaget do not represent the domain of adult scientific literacy; no naturalistic or realistic tasks are employed. Piaget became concerned about this issue when replication studies revealed that few adults could perform the original tasks successfully. He offered, as one hypothesis, that adults might achieve sophisticated reasoning only in their area of expertise. Such a viewpoint suggests very limited transferability of the skills Piaget is studying, but offers no guidance to educators concerning how to predict or enhance transfer (e.g., What is "expertise?" What aspects of "expertise" foster logical thinking?"). Explorations using a wider range of tasks are needed. The interaction between task and subject characteristics must be explored.

One difficulty with the Inhelder and Piaget tasks is that they are all presented with manipulative materials so the effect of this factor cannot be determined. Piaget has said that concrete reasoning on these tasks is characterized by "direct organization of immediately given data"; formal thinkers move from what is "real" to what is "possible" but not necessarily represented in the task.

Piaget, among others, has said that verbally presented tasks differ from manipulative tasks. Piaget suggests that verbal problems at times require a more complex scheme than manipulative problems, and gives as an example the transitive reasoning problem: "Edith is fairer than Suzanne, and Edith is darker than Lily. Who is the darkest of the three?" This problem is trivial for the seven-to-eight-year-old when the variable is length of available wooden sticks, but difficult for the fourteen-year-old when stated verbally. However, other researchers have shown that verbal problems with familiar variables are easier than manipulative problems (e.g., Levine and Linn, 1977).

Piaget's definition of "concrete" reasoning does not specify which task characteristics define a task as "demanding only direct organization of immediately given data;" This lack is critical from an educational standpoint. We do know that the verbal-manipulative demension is not isomorphic with task demands; we do not know what task dimensions are consistently related to difficulty.

Many replications of Piaget have shown that certain versions of tasks are easier than others. These task progressions are called "décalage" and are not explained by the Piagetian theory. Piaget (1971) says, on this point,

> I have often been reproached for not having produced a sufficiently precise theory of. . . time lags in the same way as one can try to produce a theory of the overall structures or of the positive characteristics of stages. But time lags are a negative characteristic which form an obstacle to the construction of the overall structures. My reply to such a reproach is merely the following: Time lags are always due to an interaction between the person's structures on the one hand, and the resistances of the object on the other. . . some resistances of objects are unpredictable. When one encounters them, one can explain them, but always after the event. It is not possible to have a general theory of these resistances (1971, p.11).

Educators need to understand task specific variance or "resistance to the object" and to relate this variance to other differences between individuals--points on which Piagetian theory does not offer guidance. Piaget's viewpoint has influenced others to despair at understanding décalage (Scardamalia, Note 1) and many to explore décalage (e.g. Odom, in press; Brainard, 1973).

Thus in many areas of importance to educators Piagetian theory is not informative. The units (e.g., task specific variance) that educators need to understand are not the units emphasized by Piagetian theory. As educators we need to understand task specific variance factors that influence transfer of learning and aptitudes that might interact with performance on complex problem solving tasks, while Piagetian theory focuses on a general developmental progression.

The second question concerns the viability of the Piagetian structural theory as a focus for a research program. Does the theory have predictive validity in a developmental domain? Intuitive or descriptive notions of stage structures may well be useful to condense the diverse knowledge we now have. Piagetian theory is just one of these. The question we need to assess is whether we have research methodology that enables us to gather information to refute Piagetian theory. Many writers (e.g. Phillips, 1978; Flavell, 1974; Flavell and Wohlwill, 1969) question whether sufficient information can be gathered to support or refute a stage structure theory. Without the capability of refutation, research in the area ceases to add new information (see Phillips and Nicolayev, 1978, discussion of Kohlberg's research program).

Others have questioned the generality of Piagetian theory, suggesting the need for additional stages to explain adult complex problem solving. Writers proposing a fifth stage for Piagetian theory point out that the description of the formal stage does not explain how individuals identify new problems (Arlin, 1975, problem finding) or develop their own logical system. (Riegel, 1973, a dialectic model.) Logicians have also questioned the consistency of Piaget's theory (e.g. Ennis, 1975; Parsons, 1960).

Thus Piagetian theory gives little consideration to the units of analysis relevant to educational problems and may lack predictive validity. What alternatives are promising? The difficulty is to develop theory at a level of

generality relevant to educational decision making. Cronbach (1973) argues that general instructional theories will always lack predictive validity because of rapid societal changes and because of our inability to realistically process second and third level interactions especially with societal variables. Both Cronbach (1973) and Snow (1977) suggest attention to instructional problems in limited environments (e.g., a single school or school district). They offer a powerful technique (aptitude treatment interaction analysis)for these investigations. This approach deserves consideration in future research relating adolescent cognitive development to instruction. Preliminary investigations would focus on the role of aptitudes in performance on adolescent reasoning tasks. These findings would then be generalized to studies employing instruction. Some evidence suggests that judiciously designed training studies such as Siegler's (Siegler and Liebert, 1975; Siegler, Liebert and Liebert, 1973), may be relevant to group instruction studies (see Linn, in press, for a discussion).

Pascual-Leone (1970; see Ammon, 1977) has offered a neo-Piagetian formulation which gives precise predictions for performance on certain complex problem solving tasks (see Scardamalia, 1977, Note 1) based on a form of task analysis. Pascual-Leone's theory specifies that development consists of an increase in processing capacity rather than the emergence of an invariant structure. Tasks are analyzed to determine what processing demands they make on the subject and predictions about who will pass and fail tasks are based on processing capacity as well as aptitude characteristics which influence whether processing capacity will be used efficiently (see Scardamalia, 1977, Note 1; and Case, 1974, 1975). Although precise prediction depends on the validity of the task analysis, the processing capacity concept offers a constraint on performance worth pursuing and the postulated role of what Pascual-Leone calls "field factors" or cognitive style appears relevant to education (e.g. Case, 1975; Linn, in press (a); Niemark, 1977). This viewpoint has especially guided some

interesting work in ability to write (Scardamalia, 1978). The neo-Piagetian theory predicts that tasks are failed when there is insufficient processing capacity for the scheme employed. Successful training then must supply schemes that require less processing capacity than the schemes employed before training. This concept deserves further research.

Many theorists, including Jim Greeno, Jerome Bruner, David Olsen, and Gabriel Solomon, suggest network theories to provide a general explanation of human information processing. These theories retain, in a sense, the equilibration concept in Piagetian theory, but omit notions of invariant structure and may or may not constrain development as neo-Piagetian theory does. Essentially, if we take schemes, as defined by Piaget, as elements in a network, these theories attempt to represent how the schemes are connected. Advances in understanding are represented by increasing and consolidating connections between schemes. A qualitative change would then be represented by a new equilibria of several schemes but would not necessarily influence all other scheme connections. Décalage is represented by continued consolidation of connections between related schemes. Instructional theorists postulate how variations in instruction could influence how information is encoded, connected, and activated in the network. This work is largely descriptive, but deserves consideration as an approach that may eventually yield predictions at an appropriate level of generality. Focus on how information is encoded at the level of the task has been successful in explaining performance on certain tasks (Siegler, 1976).

Piaget's theory, while lacking predictive validity for our current problems, has motivated much important research by describing interesting phenomena. Originally, the theory grew from Piaget's observations of his own children and later from observations and "clinical" interviews of other children. The power of naturalistic observation as a basis for theory development seems clear.

Researchers developing narrowly predictive models or theories will do well to validate them through naturalistic observations of behaviors similar to those they study experimentally. In addition, development of more powerful instructional theories will certainly benefit from naturalistic observation.

## Methodological Procedures Relevant to Research on Adolescent Reasoning

Theories cannot be pursued without the appropriate analytic research tools. Piagetian theory has relied on the clinical interview and stage scoring as the primary tool. Neo-Piagetian theory, aptitude treatment interaction research, and network conceptualizations of information processing either suggest or require different tools.

### Piagetian Theory

Focus on stage related questions has led many Piagetian oriented researchers to gather and analyze data at a very general level. It is frequent for researchers to conduct 20-minute interviews and assign one of five scores (pre-operational, early or late concrete, early or late formal) which clearly underrepresents the wealth of detail in the protocol. Some writers remedy this by presenting excerpts from protocols, following Piaget. This approach serves to highlight an issue but clearly suffers from potential unreliability. The stage scoring procedure used by followers of Piaget limits the likelihood that Piagetian theory will be questioned because the categories are broad and inconsistencies within subjects must be resolved in a single score. Even so, comparisons across adolescent reasoning tasks have revealed inconsistency in performance on tasks both within and between subjects (e.g. Lovell, 1961; Tomlinson-Keasey, 1972; Dulit, 1972; Jackson, 1965).

More detailed analysis of performance is needed to understand these

inconsistencies. Data gathering and scoring techniques somewhere between stage scores and varbatim interviews are needed. Promising avenues include structured interviews which offer subscores on specific tasks or question types (e.g., Linn and Rice, Note 6; Niemark, 1975) and design of performance based tasks which clarify task demands (e.g., Siegler, 1976; Scardamalia, Note 1). Siegler (1976) has developed tasks with clearcut performance criteria and isolated rules used to explain failures in a version of the Balance Beam task. Others have argued for performance criteria in research on complex problem solving (e.g. Brainard, 1973), but it is premature to force investigators to use performance standards which may limit the type of investigation possible. Siegler, for example, generally requests that subjects criticize or predict the outcomes of experiments done by others rather than construct their own experiments. Performance standards are generally thought to underestimate capability (e.g., Brainard, 1977), but can also result in overestimates (e.g., Linn, 1977). It is of importance to educators to find out why subjects' explanations differ from their performance rather than to arbitrarily choose one form of response or another.

These structured tasks can be designed only by first conducting naturalistic or clinical observations and interviews to isolate the relevant features of the task. Generalizability can be assured only by studying the whole range of students. Thus diverse population groups need to be used.

Task Analysis

Neo-Piagetian theory emphasizes rational task analysis as a procedure for isolating the relevant features of a task and determining the information load in a given task. This is one way to get a finer grained analysis of a complex problem solving task than is indicated by Piagetian analysis. A wide variety of task analyses procedures are available from simulations (e.g.,

Klahr's production systems) to task general decision trees (e.g., Linn and Pulos, Note 2). Task analyses have been employed by a variety of researchers from the neo-Piagetian or information processing perspective in several different ways (e.g., Scardamalia, 1977; Siegler and Atlas, 1976; Klahr and Siegler, 1976; Simon, 1972; Linn, in press (b); Linn and Pulos, Note 2). The predictive validity of a task analysis is generally amenable to direct empirical test and treats the units of information relevant to educational questions. The limitation of task analyses that have been done is that they are narrow in scope. An appropriate level of generality for task analysis in complex problem solving is one with predictive validity for education.

From the standpoint of education, researchers employing this approach should be encouraged to focus on generalizability of findings by including tasks with different subject matter and transfer tasks and by examining and comparing laboratory and natural tasks (e.g. Pulos and Linn, in press; Linn, in press, b).

Analysis of Similar Tasks

Task analysis using decision trees similar to those employed by Earl Hunt (1962) has been very helpful in clarifying the source of task specific variance in tasks purportedly measuring the controlling variables schema. As an example, let's compare some tasks measuring ability to design a controlled experiment: the Pendulum, Bending Rods, and Ramp. Many problems with Pendulum have been discussed (e.g., Linn, 1977; Pulos and Linn, 1978; Younis, 1977). A major problem that has not been previously considered concerns task directions indicating that only one variable makes a difference on Pendulum. If the subject knows that only one variable makes a difference, it is most efficient to use an elimination strategy rather than a controlling strategy. Elimination is illustrated in the task analysis in Figure 1 by taking the "Yes" branch for the top question. As can be seen, if the subject knows there is only one operative

Figure 1. Task Analysis of Several Controlling Variables Tasks

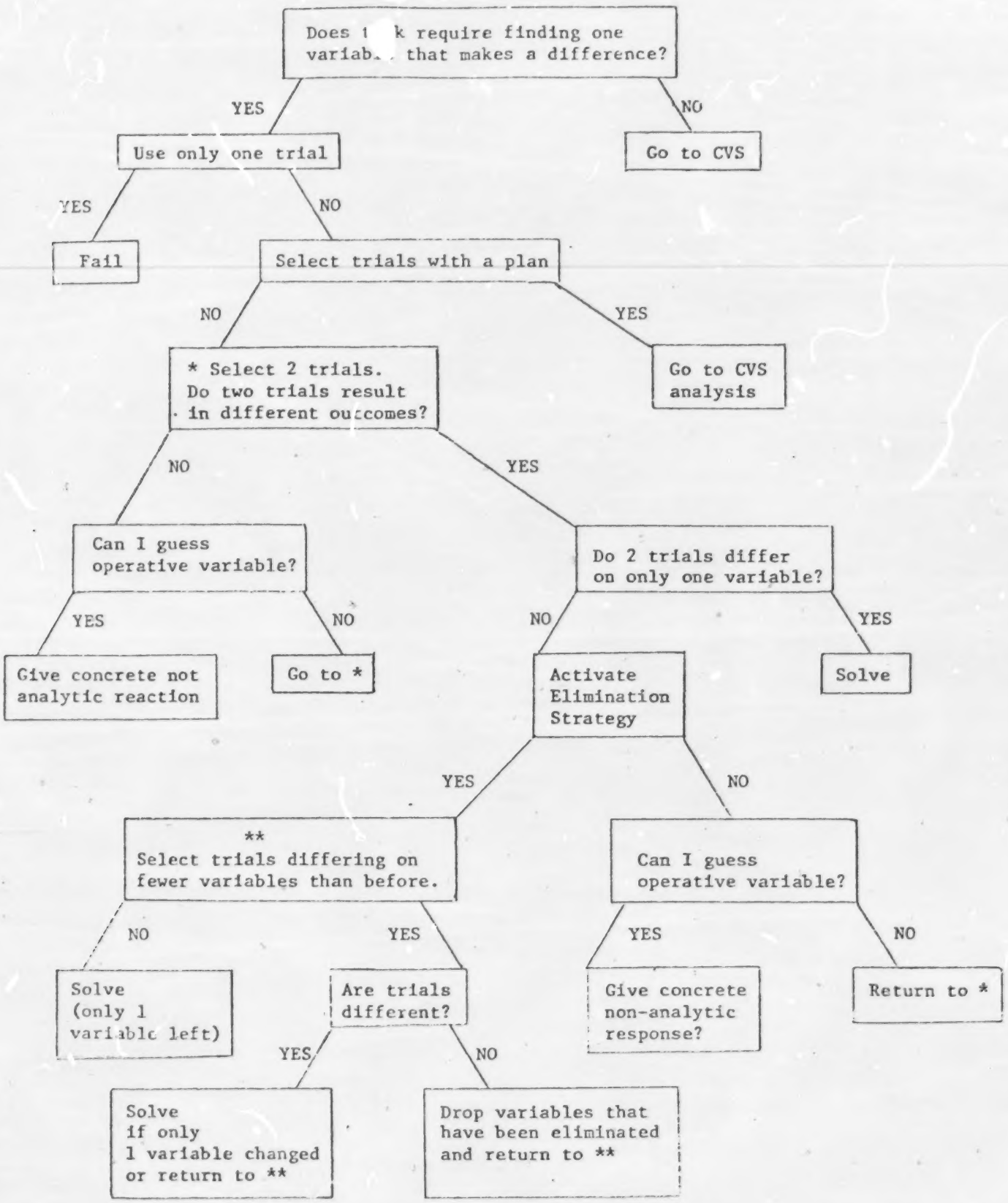
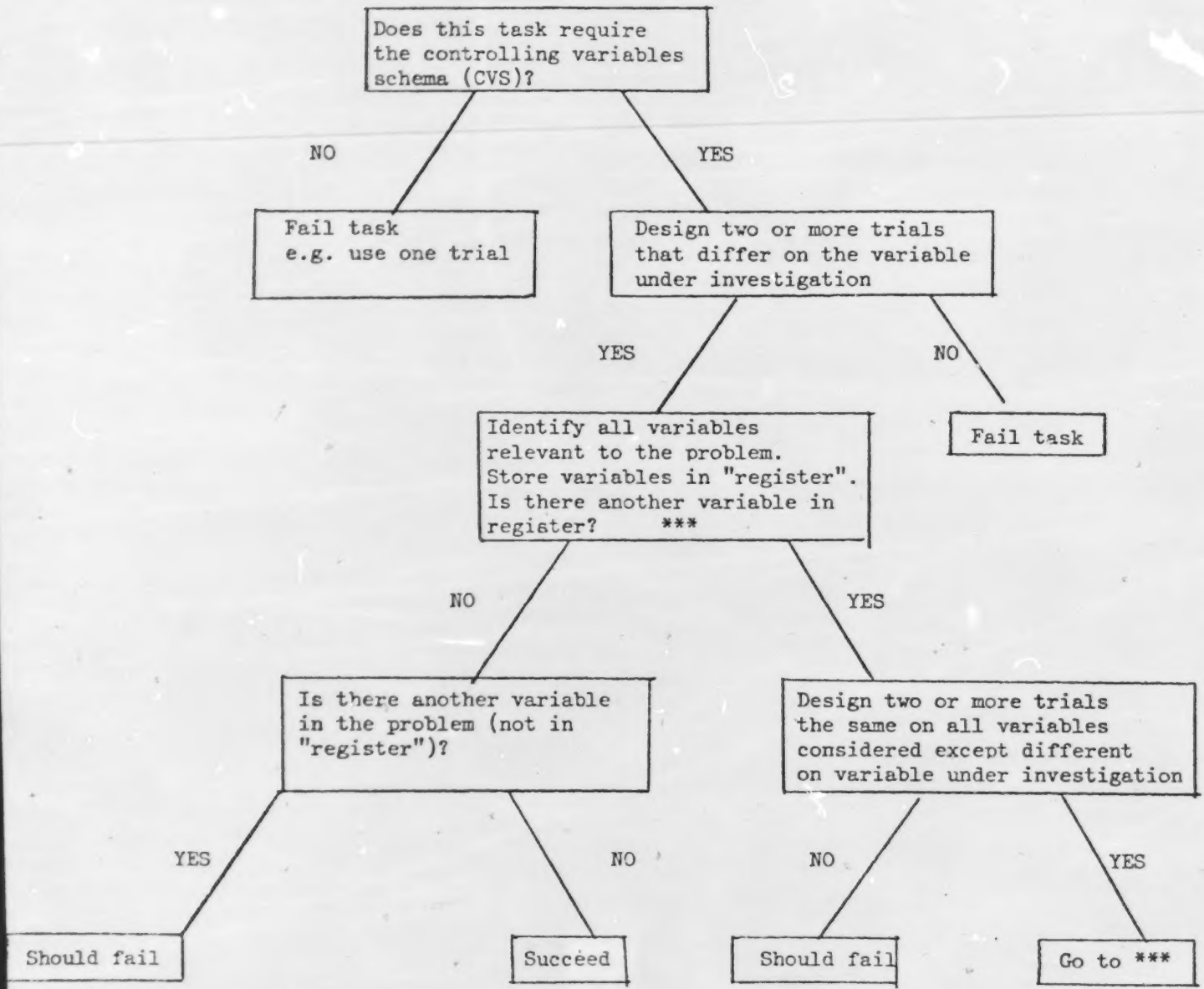


Fig. 1 (contd.) DECISION TREE

CONTROLLING TASK USING CVS


Does this task require the controlling variables schema (CVS)?
NO
YES
Fail task e.g. use one trial
Design two or more trials that differ on the variable under investigation
YES
NO
Identify all variables relevant to the problem. Store variables in "register". Is there another variable in register? ***
Fail task
NO
YES
Is there another variable in the problem (not in "register")?
Design two or more trials the same on all variables considered except different on variable under investigation
YES
NO
NO
YES
Should fail
Succeed
Should fail
Go to ***

variable, task performance is different from when many variables could be operative. Several variables can be eliminated at once, and the solution could emerge without much planning on the part of the subject.

In the same task analysis, consider Bending Rods as administered by Inhelder and Piaget (1958). This task is more difficult than Pendulum. Bendability of rods differing on five variables is investigated. All solutions to Bending Rods require the subject to employ the Controlling Variables Scheme (CVS), unlike Pendulum. An important characteristic of Bending Rods which is clarified by task analysis concerns the fact that all levels of all variables are not available. For this reason a subject might decide to do an experiment using brass rods to test for thickness only to find that brass rods differing on thickness but not cross section do not exist. To succeed, the subject would then have to give up the idea of using brass rods and seek steel rods to perform the comparison.

The Ramp task involves spheres rolling down a ramp (Linn, 1977; Levine and Linn, 1977). This task does have every level of every variable available, but discussions with subjects reveal that certain variables, especially marble size, are not considered important by subjects. This problem is illustrated in the task analysis with the "register" phenomenon.

Illustration of these systematic logical differences between tasks suggests explanations for low inter-task correlations found for complex problem solving tasks (e.g., Linn and Pulos, Note 2). Task analysis revealed problems which have not been considered in comparisons of these tasks on a more general level (e.g., Day and Stone counter balanced pendulum and bending rods in a training study.)

This task analysis also clarifies the findings of Scardamalia (1977). Following neo-Piagetian theory (Pascual-Leone, 1970), Scardamalia analyzed the task demands of a controlling variables task and predicted performance based

on the number of variables, and salience of variables, in each question. She showed that for tasks where all levels of each variable are available, and an efficient strategy is supplied, the number of variables in the task does not influence performance. The lack of an effect for number of variables seemingly contradicts findings by Wozney and Cox (Note 4) and Linn and Pulos (Note 2), but is clarified by the task analysis since the Scardamalia task where all levels of each variable are available and are independently represented on cards can be performed sequentially while the traditional version of Bending Rods, where not all levels of a given variable are available, requires keeping several variables in mind.

Analysis of Training

Task analysis has also been useful to clarify the content and likely impact of training procedures (Linn, in press b; Siegler and Atlas, 1976). Siegler and his colleagues have conducted a number of studies to show the need for conceptual training and analogue problems to enhance performance on complex problem solving tasks (Siegler and Liebert, 1974; Siegler, Liebert and Liebert, 1975). In a series of experiments Siegler (1976) analyzed the specific rules that governed performance on balance beam prediction problems and used training in rules that were ignored to show that the analysis was accurate and that training procedures can be predicted from detailed task analysis.

In a series of training studies Linn (1978) showed that the order of conceptual training and analogue problems is important, supporting a model emphasizing the means as well as the content of instruction. The task analyses verified by the experiment suggested that when the conceptual framework is presented first, subsequent learning is integrated into this framework, but when analogue problems are presented first (in a free-choice format), the information encoded by the subject hindered integration of the conceptual

framework. A reanalysis of an experiment by Kuhn and Angelev (1976) supported the results of Linn (in press, b) and Siegler and Liebert (1975) and clarified inconsistencies in Kuhn and Angelev (Linn, in press, b).

Thus, task analysis of training procedures can clarify training content and also generate predictions not intuitively obvious from a general description of the training.

The advantages of task analysis are clear in 1) providing predictions employing units relevant to educational outcomes, 2) clarifying the thinking and predictions of the experimenter, 3) enhancing communication between researchers by providing detailed information on tasks and training, 4) generating specific predictions which can be falsified (e.g. correlations between tasks).

Correlational Analysis

The aptitude-treatment-interaction approach to studying complex problem solving introduces methodological tools which have not been employed frequently in studies of adolescents.

One point that has clearly emerged in replication studies of Inhelder and Piaget's research concerns the task specific variance (décalage) associated with many of the measures employed. Task specific variance is an aspect of transfer of knowledge. If a subject displays a particular form of logical reasoning on one task, but can't display it on another, a lack of transfer is implied. Research to clarify the area of task specific variance is needed. Essentially, we need to know why schemes are activited in some instances, but not others. Also examination of characteristics of instruction or training that might lead to the more general application of a particular logical procedure is worthy of consideration. The neo-Piagetian viewpoint that similarities in performance on seemingly diverse tasks may reflect not underlying similarities between the tasks, but the existence of some other underlying characteristics of the subjects, such as a limitation in processing space available to the subject,

further justifies examination of this question. Correlational techniques are appropriate as one approach to these questions.

Linn and Pulos (Note 2) have investigated establishment task general scores by extracting the first principal factor from scores for three parallel tests. They then used multiple regression to determine which aptitude measures predicted variance on the scores. Interpretation consisted of comparisons between the multiple regression analysis and the task analysis. Thus Linn and Pulos were able to analyze aptitude-performance-interactions which might give some hints concerning appropriate interactions with instruction. Research on aptitude treatment interactions is not justified unless the character of the desired outcome is well understood and reliably measurable. Thus first priority needs to be placed on characterizing and measuring important aspects of adolescent reasoning; then studies of possible aptitude-treatment-interactions would be more likely to succeed. At the present state of our knowledge, training studies seem more suited to clarifying causes of errors in individual tasks (e.g., Danner and Day, 1978) rather than to illustrate appropriate instructional procedures.

Path Analysis or Analysis of Covariance Structures (ACOVS) deserves consideration as a methodological tool to verify predictions based on structural theories. Preliminary work by Bentley(Note 3) illustrates this approach; the data employed by Bentley were not sufficiently well defined to make interpretation of the results meaningful. Work using models analyzed by ACOVS could prove useful in unraveling the relationships between different complex reasoning tasks.

## Summary and Recommendations

Two major issues face decision makers considering future directions for research on adolescent complex problem solving. The first concerns appropriate

theoretical formulations to guide research programs; the second concerns appropriate methodological tools to gether information to develop the theories. Piagetian theory has guided most of the preliminary research but, as discussed, does not offer predictions concerning issues currently facing educators (e.g., transfer, task specific variance, instruction). No compelling alternative theory has emerged, but comprehensive studies based on neo-Piagetian theory, other information processing or network theories, and aptitude-treatment-interaction approaches deserve encouragement.

Several methodological tools fit these theories and are likely to yield useful information. Task analysis is emerging as a valid technique in adolescent complex problem solving research. The difficulty is to encourage analyses which are general enough to yield information relevant to educational problems. Rational task analysis from the subjects' viewpoint as illustrated by Pascual-Leone (1970) and used by Scardamalia (1977, Note 1) deserves further study. Multivariate analyses such as principal factor analysis to extract task general scores, regression analysis, and path analysis are likely to yield useful information when used to analyze data on complex problem solving.

Two uses for task analysis seem especially relevant. The first concerns understanding why and how information in task is encoded. The second concerns understanding why and how schemes become available to a subject and are activated. Siegler, in studying encoding of information, has found it most effective to focus his research on a single task such as Balance Beam prediction problems. Linn and Pulos in studying generalizability of schemes have found it most effective to focus on a single scheme and examine task general and task specific variance. Scardamalia has focused on a single scheme and varied task demand. Both encoding of information and activation of schemes are relevant to training and, as discussed, are likely to be clarified by training

studies. Observation of successful research programs suggests that focus on a single relatively narrow problem is most likely to enhance understanding of broader educational problems.

Understanding of activation of schemes has been shown to be advanced by examination of aptitude performance interactions using multivariate techniques. It would be advantageous to examine encoding of information in terms of aptitude variables. Field dependence/independence has shown special promise as an aptitude variable relevant to encoding.

To understand how to design instruction in adolescent reasoning, researchers would do well to focus on understanding the development of adolescent reasoning ability including the likely causes of failure on tasks studied. For example, it would be appropriate to determine whether better understanding of the variables would foster ability to control variables and whether problems relevant to personal decision making (e.g., buying a car) are failed for the same reasons as tasks with physical variables (e.g., Pendulum). This information could then be used by curriculum developers to design curriculum programs for schools. Evaluation of the curriculum programs would then be the appropriate place to use results from aptitude performance interactions to design studies of possible aptitude treatment interactions. Group training studies have the same lack of generalizability as most evaluation studies. In both cases variance associated with teachers, group composition, and program implementation make generalizability of the results to other teachers, schools, and programs limited. It is far more efficient to conduct training studies using available curricula so, at least, the results are generalizable to a similar set of surriculum materials. Thus training studies are most likely to be effective if they focus on clarifying task performance; instruction is most likely to be influenced by studies aimed to influence curriculum developers and by evaluation of curriculum developments.

Concern with task general and task specific variance argues strongly for all researchers to employ two or more measures of the same task (Campbell and Fisk 1959). Availability of standardized or marker tasks seems promising, but rarely succeeds, seemingly because such tasks are not taken as seriously as the tasks of interest to the researcher. Clearly standardized or marker tasks, if available, would be used in evaluation studies and for clinical diagnosis.

## Reference Notes


NOTE 1: Scardamalia, M. The Interaction of Perceptual and Quantitative Load Factors in the Control of Variables. Paper presented at SRCD regional conference, San Francisco, February, 1978.

NOTE 2: Linn, M.C. and Pulos, S. Adolescent Reasoning: Aptitude Performance Interactions in Formal Thought. Lawrence Hall of Science Report, 1978.

NOTE 3: Bentley, W. An Exploration of Structuring in the Stage of Formal Operations. Paper presented at Jean Piaget Society Meeting, May, 1977, Philadelphia.

NOTE 4: Wozney, C.D. and Cox, D.L. The Effects of Task Differences on the Assessment of Formal Thinking. Paper presented at AERA, Washington D.C., April, 1975.

NOTE 5: Day, M.C. and Stone, A. Personal communication, Psychology Department, University of Houston.

NOTE 6: Linn, M.C. and Rice, Marion. A Measure of Ability to Control Variables: The Springs Task. Unpublished manuscript (AESOP report PSC-22), Lawrence Hall of Science, University of California, Berkeley, 1977.

## References


Ammon, P.R. Cognitive Development and Early Childhood Education: Piagetian and Neo-Piagetian Theories. In H. L. Hom and R. R. Robinson (eds.), Psychological Processes in Early Education. New York, Academic Press, 1977.

Arlin, P. Cognitive Development in Adulthood. A fifth stage? Developmental Psychology, 1975, 11, 602-606.

Brainard, C.J. Order of Aquisition of Transitivity, Conservation, and Class Inclusion of Length and Weight. Developmental Psychology, 1973, 8, 105-116.

Brainard, C.J. Response Criteria in Concept Development Research. Child Development. 1977, 48, 360-366.

Campbell, P.T. and Fiske, D.W. Convergent and Discriminant Validation by the Multitrait-Multimethod Matrix. Psychological Bulletin. 56, 1959, 81-105.

Case, R. Structures and Strictures: Some Functional Limitations on the Course of Cognitive Growth. Cognitive Psychology, 1974, 6, 544-573.

Case, R. Gearing the Demands of Instruction to the Developmental Capacities of the Learner. Review of Educational Research, 1975, 45, 59-87.

Cronbach, L.J. Two Disciplines of Scientific Psychology. American Psychologist, 12, 1957, 671-684.

Cronbach, L.J. Beyond the Two Disciplines of Scientific Psychology. American Psychologist, 1975, 30, 116-127.

Danner, F. W. and Day, M.C. Eliciting Formal Operations. Child Development, 1978.

Dulit, D. Adolescent Thinking á la Piaget: The Formal Stage. Journal of Youth and Adolescence, 1972, 1, 281-301.

Ennis, R. H. Children' Ability to Handle Piaget's Propositional Logic: A Conceptual Critique. American Education Research Journal, 1975, 45, 1-41.

Flavell, J.H., and Wohlwill, J.F. Formal and Functional Aspects of Cognitive Development. Elkind, J. and Wohlwill, J.F. (Eds.), Studies in Cognitive Development, London, Oxford University Press, 1969.

Glaser, R. Congitive Psychology and Instructional Design. In D. Klahr (Ed.) Cognition and Instruction. Hillsdale, New Jersey: Lawrence Erlbaum Associates, 1976.

Hunt, E. Concept Learning: an Information Processing Approach. New York, Wiley, 1962.

Inhelder, B. and Piaget, J. The Growth of Logical Thinking from Childhood to Adolescence (A Parsons and S. Milgram, trans.). New York: Basic Books, 1958.

Jackson, S. The Growth of Logical Thinking in Normal and Subnormal Children. British Journal of Educational Psychology, 1965, 35, 255-258.

Klahr, D. and Siegler, R.S. The Representation of Children's Knowledge. (working draft) April 16, 1976. In M. Reese and Lipsitt (Eds.), Advances in Child Development and Behavior, Vol II, 1976.

Kerst, S. and Youniss, J. Complexity of the Pendulum Problem. The Formal Operator, Vol I, 1977.

Levine, D. and Linn, M.C. Scientific Reasoning Ability in Adolescence: Theoretical Viewpoints and Educational Implications. Journal of Research in Science Teaching, 1977, 14, 371-384.

Linn, M.C. Scientific Reasoning: Influences on Task Performances and Response Categorization. Science Education, 1977 a, 61, 357-369.

Linn, M.C. Cognitive Style, Training and Formal Thought. Child Development, in press a.

Linn, M.C. Teaching Students to Control Variables: Some Investigations Using Free Choice Experiences. In Modgil, S. and Modgil C, (Eds.) Toward a Theory of Psychological Development Within the Piagetian Framework, in press b.

Linn, M.C. and Levine, D.I. Adolescent Reasoning: The Development of the Ability to Control Variables. Science Education, in press.

Lovell, C. A Follow-up Study of Inhelder and Piaget's The Growth of Logical Thinking. British Journal of Psychology, 1961, 52, 143-153.

Neimark, E.D. Intellectual Development During Adolescence. In Frances Degen Horowitz, ed., Review of Child Development Research, Vol 4, University of Chicago Press, 1975 a, 541-594.

Neimark, E.D. Longitudinal Development of Formal Operations Thought. Genetic Psychology Monographs, 1975 b, 91, 171-225.

Neimark, E.D. Toward the Disembedding of Formal Operations from Confounding with Cognitive Style. Paper presented at meeting of the Piaget Society, Philadelphia, May 1977. Report No. 26, Douglass College, State University of New Jersey.

Olom, R.D. A Perceptual-Saliance Account of Decalage Relations and Developmental Change. In C. J. Brainerd and L.S. Siegel (Eds.), Alternatives to Piaget: Critical Essays on the Theory. New York: Academic Press, in press.

Pascual-Leone, J. A mathematical model for the transition rule in Piaget's developmental stages. Acta Psychologia, 1970, 63, 301-345.

Phillips, D.C. The Piagetian Child and the Scientist: Problems of Assimilation and Accomodation. Educational Theory. 1978.

Piaget, J. The Theory of Stages in Cognitive Development, pp. 1-11 in Green, D.R., Ford, M.P. and Plamer, G.B. (eds.), Measurement and Piaget. New York: McGraw Hill, 1971.

Piaget, J. Intellectual Evolution from Adolescence to Adulthood. Human Development, 1972, 15, 1-12.

Phillips D.C. and Nicolayev, J. Kohbergian Moral Development: A Progressing or Degenerating Research Program. D. Cochrane, C. Hamm, and A.C. Kazepides (eds.). The Domain of Moral Education, in press.

Pulos, S. and Linn, M.C. Formal Operations: Fact or Artifact? Proceedings of the 8th Annual UAP-USC Conference on Piaget and the Helping Professions. 1977, in press.

Pulos, S. and Linn, M.C. Pitfalls and Pendulums. Formal Operator, Winter, 1978.

Riegel, Klaus. Dialectic Operations: The Final Period of Cognitive Development. Human Development, 1973, 16, 346-370.

Scardamalia, M. How Children Cope with the Cognitive Demands of Writing. In Frederickson, C.H. Whiteman, M.F. and Dominic, J.F. (eds.) Writing: The Nature, Development and Teaching of Written Communication, in press.

Scardamalia, M. Information Processing Capacity and the Problem of Horizontal Decalage: A Demonstration Using Combinatorial Reasoning Tasks. Child Development, 1977, 48, 28-37.

Siegler, R.S., Liebert, D.E. and Liebert, R.M. Inhelder and Piaget's Pendulum Problem: Teaching Preadolescents to Act as Scientists. Developmental Psychology, 1973, 9, 97-101.

Siegler, R.S. and Liebert R.M. Acquisition of Formal Scientific Reasoning by Ten-and Thirteen-Year-Olds: Redesigning a Factorial Experiment. Developmental Psychology, 1975, 11, 401-402.

Siegler, R.S. Three Aspects of Cognitive Development. Cognitive Psychology, 1976, 8, 481-520.

Siegler, R.S. and Atlas, M. Acquisition of Formal Scientific Reasoning by Ten and Thirteen Year Olds. Journal of Educational Psychology, 1976, 68, 360-370.

Simon, H.A. On the Development of the Processor. In Sylvia Farnham-Diggory (ed.), Information Processing in Children. New York: Academic Press, 1972, 3-22.

Snow, R.E. Individual Differences and Instructional Theory. Educational Researcher, 1977, 6, 11-15.

Tomlinson-Keasey, C. Formal Operations in Females from Eleven to Fifty-four Years of Age. Developmental Psychology, 1972, 6, 364.

Parsons, C. Inhelder and Piaget's The Growth of Logical Thinking: II A Logician's Viewpoint. British Journal of Psychology, 1960, 51. 75-84.